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FINAL REPORT

NAVAL RESEARCH LABORATORY
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PRELIMINARY DATA SYNTHESIS IN SUPPORT OF AN ACOUSTIC NATURAL LABORATORY ON THE EAST PACIFIC RISE

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Final Report, MK006, "Preliminary Data Synthesis is Support of an Acoustic Natural Laboratory on the East Pacific Rise"

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by

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At the present time the Navy-supported oceanographic community is embarking on a major program of investigation into the nature of bottom roughness and its role in the propagation of low frequency sound in the ocean. This multi-disciplinary long-term initiative, the Bottom/Subbottom Special Research Program (SRP), will focus on a Western North Atlantic Natural Laboratory site with detailed field work using a variety of seafloor mapping systems, at a substantial cost.

In this small study we have performed a synthesis of the seafloor data on hand for the East Pacific Rise as a preliminary analysis of the resolution of the seafloor mapping systems used by the oceanographic community, particularly with respect to bottom slopes and scales of detectable features. Geologists generally consider

It is to be noted that in the geological community the terrain of the slow-spreading Mid-Atlantic Ridge as 'rough' is generally considered "rough," while that of the fast-spreading East Pacific Rise is considered "smooth." This conception may be misleading in terms of the steepest slopes and the small scale features which govern low frequency backscatter. Initial calculations of the roughness of relief, as computed by the amount of vertical relief per km of seafloor measured by Deep Tow (UCSB work in progress), show that the fastest spreading EPR is almost as rough as the slowest spreading MAR, and that both are much rougher than profiles from intermediate rates. This report includes a paper on three-dimensional bathymetric imaging.

With the advent of swath mapping systems, the mid-ocean ridges were found to have curious overlapping spreading centers and other deviations from axial linearity. Dozens of expeditions later, and with the combined efforts of geophysicists, geologists, petrologists, seismologists, mathematicians and even biologists, a picture is beginning to emerge of how the fabric of the oceanic crust is created and evolves, and how segmentation along the ridge is related to underlying processes in the upper crust and even to mantle convection [Macdonald, et al, 1988].

DIGITAL MAP MAKING AT UCSB

One of our goals at UCSB has been to create a comprehensive digital data base of all the available swath mapping bathymetry on the East Pacific Rise from 17 N to 23 S. Because many of the geological processes we wish to investigate are recorded in the detailed fabric of the oceanic crust, we have chosen a very fine sample spacing, 200 m, for our archival gridded data sets. At a coarser spacing, the subtle details of the axial ridge morphology begin to get lost, especially when filtered by contouring algorithms.

For each individual SeaMARC II ping, the depth estimates are subjected to several error-rejection filters in our post-processing software. For smoothness, the navigation track is approximated by spline polynomials. Desired swath data can be selected by a "scissoring" operation. Data points which have passed through the error rejection and data selection filters are then distributed to a neighborhood of output grid nodes. The weighting function is of the form 1/(A**2+R**2), where R is the distance between the data point and the grid node, and A is used to control the shape of the weighting function.

The bathymetric data from the two different sonar systems, Sea Beam and SeaMARC II, are processed independently until the very last stages, as they have different signal and noise characteristics and were obtained on separate cruises. Most of the SeaBeam data used in this study were obtained already gridded from

the URI synthesis [Tighe, et. al, 1988], at a sample spacing of approximately 200 m. Once the Sea Beam and SeaMARC II bathymetric data have been gridded, they can be combined on a grid cell by grid cell basis. Priority is given to the Sea Beam data in the sense that if both data exist for a grid cell, the SeaMARC II point is ignored and the Sea Beam point is used in the final output grid.

The UCSB combined synthesis of SeaBeam and SeaMARC II bathymetry for the northern half of the EPR is about to be published in Marine Geophysical Researches, [Macdonald, et al, submitted]. It will include a color-fill contour map series, with 50 m contours, based on color separation masks created on a CalComp color electrostatic plotter.

The software which performs this digital map-making at UCSB is being made available to NRL. The VAX/VMS version can be copied across the Internet from our MicroVAX (128.111.254.22), from millib@sbugel.ucsb.edu. The evolving Unix version can be copied from our Sun (128.111.254.108), miller@magic.ucsb.edu.

PROVIDING ENVIRONMENTAL GROUND TRUTH: EXISTING DATA AT UCSB

The UCSB marine geophysical data collection includes seafloor relief spanning spreading rates from 20 to 160 mm/year and a wide range of crustal ages (Table 1). These data sets include SASS, SeaBeam, SeaMARC I and II, Gloria, Deep-Tow and submersible observations. We have all of these types of data at several locations on the Mid-Atlantic Ridge and the East Pacific Rise out to distances of 100-1000 km off-axis. In addition the available single channel seismic data have been acquired, to provide profiles of sediment thickness crossing the ridge and extending hundreds of km to deep ocean basin regimes.

To illustrate the quality of data in hand, and the wide variety of morphotectonic texture found on the seafloor, in this report we have included a 3-D shaded relief image of a regridded dataset from the EPR at 9 N. SeaMARC II data from our ONR-funded MW8706 cruise make up the bulk of the coverage, and are integrated into Sea Beam data from the URI synthesis as well as the carefully navigated SeaBeam survey. The sample spacing is 200 m, and the area is 130 x 230 km in size. In addition from our 1983 expedition we have extensive Deep Tow data at this site, which calibrate the slope resolution of the swath data. Further near bottom photographic, sidescan and rock sample data were acquired in Nov-Dec 1989 Haymon/Fornari cruise with the WHOI Argo system, and are being integrated into our Deep Tow, SeaBeam and SeaMARC II data at 9 N.

Statement "A" per telecon Dr. Joseph Kravitz. ONR/Code 1125GG

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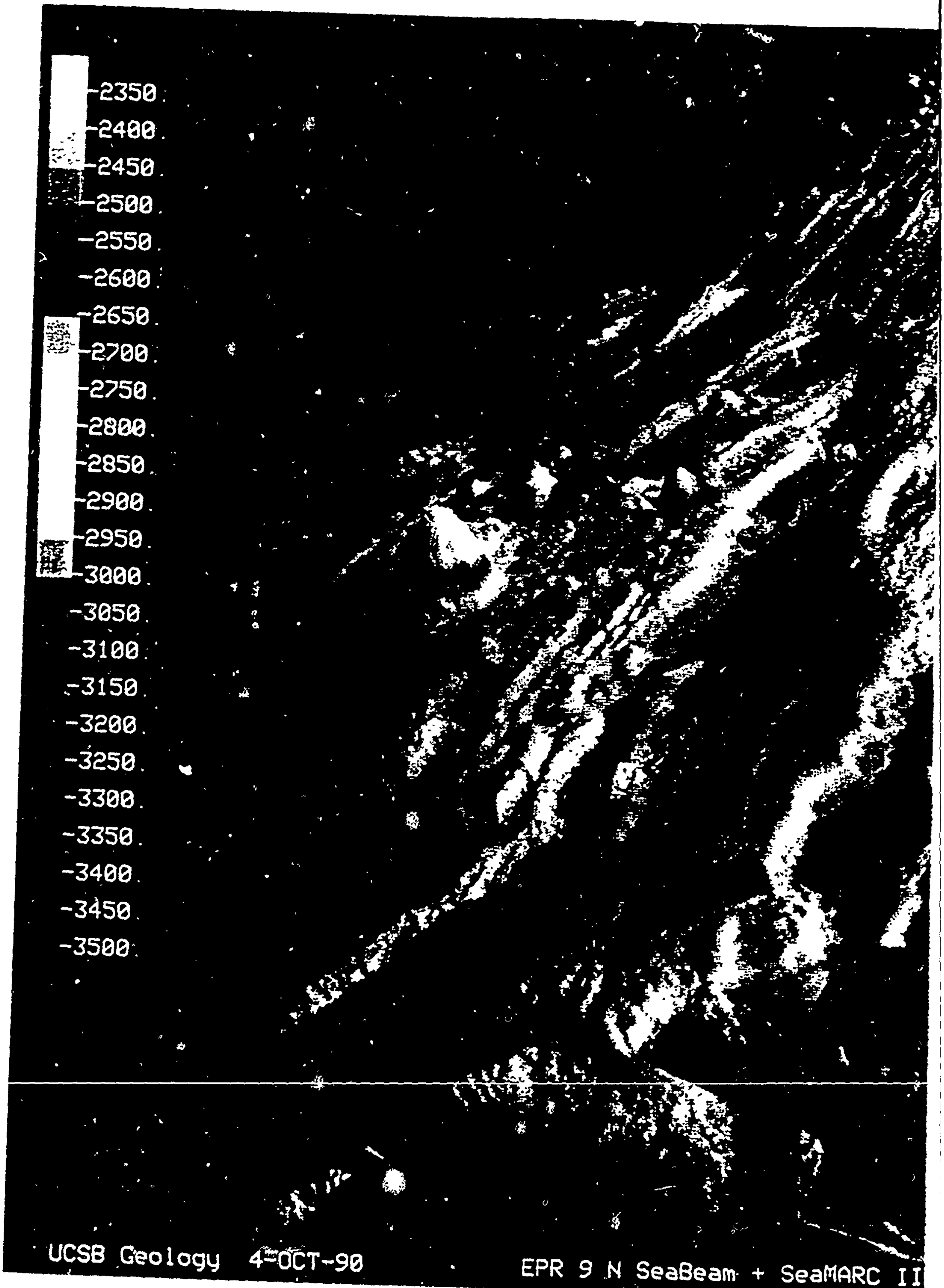
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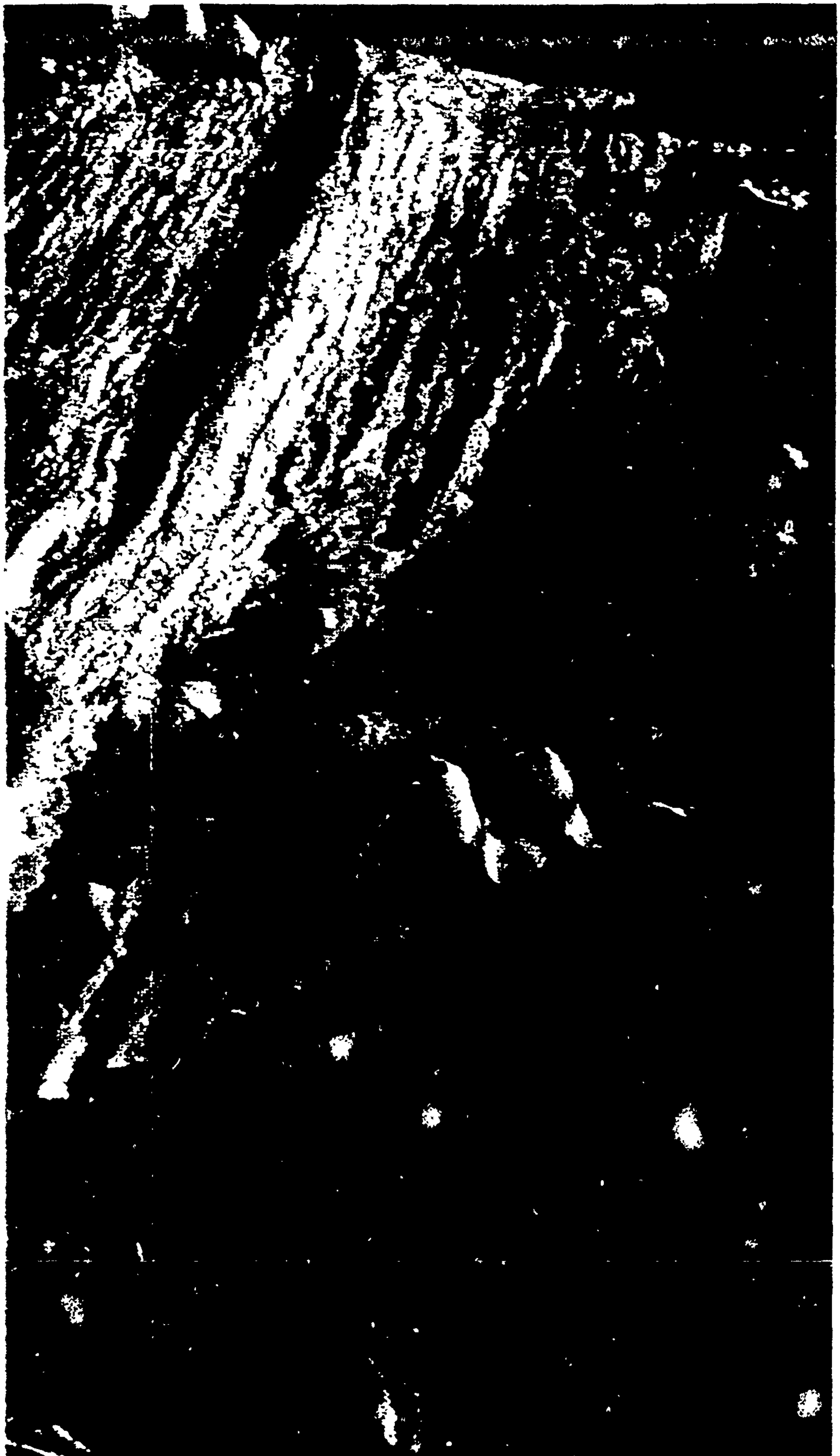
EPR 9 N SeaBeam + SeaMARC II



ARC II (looking NW)

Table 1.

High Resolution Seafloor Mapping Data at UCSB

Year	System	Spreading (full rate, mm/yr)	Location	Project	Vessel
1973	Deep-Tow	22	MAR 37.5 N	Fine scale studies of volcanism and tectonism at a slow spreading center. (Macdonald Ph.D. thesis cruises, 2 legs)	Knorr
1977	Deep-Tow	65	EPR 21 N	Morphology of intermediate rate spreading center. Detailed near bottom magnetic reversal observations.	Melville
1978	Deep-Tow	17	Red Sea	Morphology of initial spreading, slow rate.	Melville
1978	Alvin	22	MAR 37.5 N	First hand observations of rift valley and mountains. (AMAR expedition, 2 legs)	Knorr, Lulu
1979	Deep-Tow	65	EPR 21 N	Survey in preparation for Alvin RISE expedition, also detailed morphology of Tamayo transform fault.	Melville
1979	Alvin	65	EPR 21 N	Detailed geophysical experiments on intermediate spreading center, discovery of 350 dec C hot vents and biological community, magnetic reversal studies of individual basalt pillows. (RISE expedition, 2 legs)	Melville, Lulu
1981	Deep-Tow	25	Vema Transform	Morphology of slow slipping transform fault, and MAR intersection	Gyre
1982	Sea Beam	90-120	EPR 8-18 N	Swath mapping of the crest of the East Pacific Rise, discovery of Overlapping Spreading Centers.	T. Washington
1982	Deep-Tow Sea Beam	58	Galapagos 95.5 W	Morphology of propagating rift/dying rift system, Near bottom magnetic survey of prop. rift tip.	T. Washington
1983	Deep-Tow	110-120	EPR 9 N, 11.75 N	Near bottom studies of OSC's.	Melville
1983	Deep-Tow	162	EPR 20 S	Volcanism vs. tectonism at ultra fast spreading rate, near bottom studies of a magnetic reversal and small sea floor features, discovery of dueling propagator.	Melville
1984	Sea Beam	35	MAR 30-34 S	First Sea Beam studies of the Mid-Atlantic Ridge in the South Atlantic.	T. Washington
1985	Alvin	58	Galapagos 95.5 W	Volcanism and faulting in propagating rift, dying rift, and shear zone. In-situ magnetic measurement of tectonic rotation at outcrop level.	Atlantis II
1985	Alvin	120	Clipperton transform fault	Morphology of fast-slipping transform fault, interplay of volcanism and tectonism and ridge/transform intersection.	Atlantis II
1987	Sea Beam	35	MAR 24-28 S	Continuation of Sea Beam studies of Mid-Atlantic Ridge in South Atlantic.	Conrad

1987	SeaMARC II	95-120	EPR 8-18 N	SeaMARC II coverage of crest of EPR n. of equator, with major surveys at OSC's:	Moana Wave
		95	16 N		
		110	11.75 N		
		120	9 N		
1987	SeaMARC II		EPR, Galapagos	SeaMARC II coverage of crest of EPR (0-23 S) also Galapagos spreading center (85 - 89.5 W):	Moana Wave
		60	85 W	Ecuador Spreading Center and Inca Transform (Spreading, transform and pull-apart tectonic fabrics).	
		70	87.5 W	Large OSC / propagating rift on Galapagos Spreading Center.	
		152	EPR 3 S	Time series study of faulting on EPR flank, out to 5 my.	
		162	EPR 18 S	Fully inflated ridge, robust magma budget.	
		162	EPR 20.5 S	Dueling propagator, disrupted lithosphere.	
1989	Argo	120	EPR 9-10 N	Total acoustic and photographic coverage of EPR ridge axis from altitude of 20 m (transponder nav)	T. Washington

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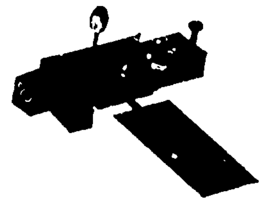

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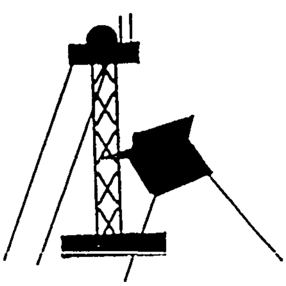

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3-D Bathymetric Imaging: State of the Art

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Abstract

Developments in bathymetric imaging have been driven by innovations in swath mapping sonar systems and computer graphics hardware. The advent of new beam forming and interferometric sonar systems has resulted in the discovery of a host of new geological phenomena. Specialized computer graphics hardware allows rapid display of complex color 3-D shaded relief images, with the specification of surface properties, light source positions. Hardware continues to evolve, with affordable 300 mips 3-D image processing systems now available. Software standards are finally emerging. Examples are drawn from recent UCSB expeditions which have explored the mid-ocean ridges, as displayed on a Raster Technologies 3-D graphics system.

Sonar Systems: Sea Beam, SeaMARC II, and Newer Hardware

Starting at the Scripps Institution of Oceanography, in the early 1980's Sea Beam swath mapping systems [1,2] began to be used in the US academic oceanographic fleet. The Sea Beam system, made by General Instrument Corporation, forms a swath made up of 16 narrow beams, each 2-2/3 deg wide, a resolution beyond the reach of the conventional single-channel echosounders which had been in use for decades. Sea Beam and other beam-forming sonars are currently being operated by researchers in France, Germany, Japan, Australia and the Soviet Union.

In the last few years the Sea Beam data in the academic community have been augmented by SeaMARC II side scan sonar data [3,4] with dramatically wider swaths, 10 km as opposed to about 3 km. In addition to high-resolution (5 m) side-scan backcatter information, these systems work in an interferometric mode to obtain bathymetry at a sample spacing of about 70 m. For the ultimate in resolution and swath width, several expeditions are being conducted in the next year on the East Pacific Rise and on the Mid-Atlantic Ridge, with combined beam-forming and sidescan systems on board.

Digital Map Making

With the new swath mapping systems, the mid-ocean ridges were found to have curious overlapping spreading centers and other deviations from axial linearity. Dozens of expeditions later, and with the combined efforts of geophysicists, geologists, petrologists, seismologists, mathematicians and even biologists, a picture is beginning to emerge of how the fabric of the oceanic crust is created and evolves, and how segmentation along the ridge is related to underlying processes in the upper crust and even to mantle convection [5,6].

One of our goals at UCSB has been to create a comprehensive digital data base of all the available swath mapping bathymetry on the East Pacific Rise from 17° N to 23° S. Because many of the geological processes we wish to investigate are recorded in the detailed fabric of the oceanic crust, we have chosen a very fine sample spacing, 200 m, for our archival gridded data sets. At a coarser spacing, the subtle details of the axial ridge morphology begin to get lost, especially when filtered by contouring algorithms.

For each individual SeaMARC II ping, the depth estimates are subjected to several error-rejection filters in our post-processing software. For smoothness, the navigation track is approximated by spline polynomials. Desired swath data can be selected by a "scissoring" operation. The remaining good data points are then distributed to a neighborhood of output grid nodes. The weighting function is of the form 1/(A**2+R**2), where R is the distance between the data point and the grid node, and A is used to control the shape of the weighting function.

The bathymetric data from the two different sonar systems, Sea Beam and SeaMARC

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II, are processed independently until the very last stages, as they have different signal and noise characteristics and were obtained on separate cruises. Most of the SeaBeam data used in this study were obtained already gridded from the URI synthesis [7], at a sample spacing of approximately 200 m. Once the Sea Beam and SeaMARC II bathymetric data have been gridded, they can be combined on a grid cell by grid cell basis with priority given to Sea Beam data.

Advances in Computer Graphics

The spatial bandwidth of the new data provided a challenge to the computer graphics capabilities of the 1980's. In geology, both the broad scale structures and the fine grain tectonic character of the sea floor are important in understanding the underlying processes and how they evolve through time. In recent years innovations in computer graphics technology have allowed the realistic display of large amounts of data. Specialized hardware has been developed by several vendors, which allow rapid display of 3-D shaded relief images, with the specification of surface properties, light source positions, and the indication of depth by color interpolation.

The software to drive the specialized hardware has been evolving, from code which was specifically tailored to certain display devices from individual vendors, to libraries of routines which can support a broad spectrum of hardware. Needless to say, the software evolution from one level to another is not always painless. For example, the 3-D visualization work at UCSB and URI is performed on Raster Technologies hardware, which was considered to be state-of-the-art in speed and functionality when it was purchased about 4 years ago. Since Alliant computer merged with Raster Technologies, speed has dramatically improved, by 1-2 orders of magnitude, but none of the existing software works on the new systems. The new machines are built around firmware optimized for PHIGS+ code, an international standard which allows the same advanced functionality in realistic 3-D rendering, but which makes it available to a wide variety of workstations. This standard is supported from most of the popular computer vendors, such as Alliant, DEC, Sun, IBM, Evans and Sutherland, etc. A revised version of our 3-D software is running on the Alliant VFX machine at the Hawaii Institute of Geophysics, and will be available to the network of Sun workstations.

Further innovations are being made at the frontier between image processing and graphics. For example, a single board from Vitec, Inc. can be placed in Sun or other workstations to allow 3-D rendering of digital terrain models, with image information such as side scan sonar texture overlaid. This system operates with a speed of 300 mips. Software standards for image processing are beginning to evolve.

Several examples of the exploration of the East Pacific Rise and the Mid-Atlantic Ridge will be presented as part of work in progress at UCSB, as displayed on a Raster Technologies 3-D graphics system. Most of the presentations are 3-D shaded relief images of bathymetry, although in addition sidescan texture or rock magnetization can be displayed as a 3-D overlay on bathymetry.

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Figure 1. A black and white rendition of a color 3-D shaded relief image is shown of regridded Sea Beam bathymetry. The view is to the north along the East Pacific Rise, as it intersects the Clipperton Transform Fault. The data span an area of approximately 90 x 50 km, at a sample spacing of 200 m. The light source, shading and 3-D geometry calculations were performed on a Raster Technologies One/380 graphics system.